

UNIVERSITÉ DE MONTRÉAL

TRANSFER CENTERS
FOR THE
TRANSPORTATION OF THE HANDICAPPED

by

Jacques Desrosiers and François Soumis

CENTRE DE RECHERCHE SUR LES TRANSPORTS



CASE POSTALE 6128, SUCCURSALE A, MONTRÉAL, QUÉBEC, H3C 3J7

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SUMMARY

The transportation service for the handicapped provides transportation for handicapped persons who are unable to use regular public transport. The present service provides door to door transportation i.e. the handicapped person is picked up by a minibus at his/her place of origin and taken all the way to his/her destination in the same vehicle. The schedule for the service is modified each day to meet regular and occasional demand as well as last-minute requests.

We examine here the possibility of introducing transfer centers. Logically, these centers could increase the productivity of this type of service as the same vehicle could then pick up at the same time all handicapped persons whose places of origin are in the same area even though they might have different destinations. In the same way, at the transfer center, handicapped persons with destinations in the same zone around the same time would be assigned to the same minibus.

A system with transfer centers would also have the advantage of facilitating the mathematical solution of the route construction problem, by decomposing it into two distinct parts: collection routes, and delivery routes subject to desired departure and arrival times. Our group has considerable expertise with routing problems involving scheduling constraints and we have developed an optimal solution method. With some modifications, the method could be applied to the problem of transportation of the handicapped.

SOMMAIRE

Le service de transport des handicapés vise à procurer un transport à toute personne handicapée incapable d'utiliser le service de transport urbain régulier. Le service actuellement offert est un service de transport du type porte à porte, où la personne handicapée est prise en charge à son origine par un minibus et est conduite à sa destination par ce même minibus. L'horaire de ce service de transport s'adapte chaque jour aux demandes régulières et occasionnelles et aux requêtes de dernière heure.

Nous proposons d'étudier la possibilité d'introduire des centres de correspondance. Logiquement, ces centres permettraient d'augmenter la productivité de ce type de service puisqu'un même véhicule pourra prendre en charge vers la même heure des personnes handicapées ayant une zone d'origine commune sans pour autant avoir la même destination. De même, à un centre de correspondance, les personnes handicapées ayant une zone de destination commune vers la même heure, seront affectées au même minibus.

Le système avec centres de correspondance a aussi l'avantage de faciliter la résolution mathématique de la fabrication des routes en décomposant le problème en deux parties distinctes: les routes de ramassage et les routes de livraison sujet à des heures de départ et d'arrivée désirées. Notre équipe a acquis une bonne expertise sur les problèmes de routes de véhicules satisfaisant des contraintes d'horaires où nous avons développé une méthode de résolution optimale. Elle devrait s'appliquer au transport des handicapés après quelques modifications.

1. INTRODUCTION

1.

The transportation service for the handicapped ensures access to public transportation for all at the same cost. This service is necessary as it is difficult for many handicapped persons to use the regular bus and metro services. We propose a reorganization of the service which would increase its productivity, with a view to increasing the accessibility of the service in the future by carrying more people or by extending the territory covered.

2. THE PRESENT SERVICE

2.1 Description

Two types of minibus transportation services for handicapped persons are presently offered: regular transportation, and occasional transportation on demand. The regular demand determines the regular daily trips made, while occasional requests registered a few days in advance, and last-minute needs are fitted into the regular schedules.

Each request consists of a place of origin with a corresponding departure time interval, and a destination with an arrival time interval. The average times required for embarkation, disembarkation and movement of a vehicle between two stops are known. A minimum number of routes must be constructed which visit all origins and destinations within the desired time intervals while ensuring that all persons are transported and the capacity of the vehicle is not exceeded. The problem must be treated dynamically, as some requests occur during operations.

With these constraints, the construction of productive routes is practically impossible. It is only possible to pick up at the same time with the same vehicle, people in the same origin zone with the same departure time and with destinations in the same direction. In a low density area, it is almost impossible to build up groups of several people satisfying all of these three requirements. In a research paper [5], it is noted that on average, over 50 requests per day are refused at the MUCTC⁽¹⁾ (over 450 people transported) and last minute changes reduce the efficiency of the service offered (cancellation rate of 20%) and increase the number of cancellations. The occupancy rate of vehicles is low (1.3 persons/hour/vehicle) as it is not permissible to make the large detours which would result from transporting groups of people with different requirements.

From an operational point of view, several drivers do overtime unnecessarily or wait for minibuses to become available at the beginning of the day. It is in fact very difficult to establish driver schedules to fit in with the daily variations in demand. With the increase in number of persons transported and the extension of the territory covered, it will become important to increase the productivity and reliability of this type of service.

2.2 Mathematical formulation

Consider a set of n requests. With each request i is associated:

- an origin i with a pick-up time t_i to take place within a departure time interval $[\alpha_i, \beta_i]$, and an integer value $\gamma_i \geq 1$ representing the number of people to be transported
- a destination $n+i$, with a delivery time t_{n+i} to occur within the arrival time interval $[\alpha_{n+i}, \beta_{n+i}]$, and a number $\gamma_{n+i} = -\gamma_i$.

(1) Montreal Urbain Community Transit Commission

The set of origins and destinations forms a network of $2n$ nodes to which must be added two nodes for the arrival and departure of vehicles from the garage (g and g'). The average travel time between stops i and j is denoted by t_{ij} where this time includes embarkation time if i is the origin, or disembarkation time if i is the destination. The set I of arcs contains all pairs (i,j) satisfying the relation

$$\alpha_i + t_{ij} \leq \beta_j \quad i, j = 1, 2, \dots, 2n \quad (1)$$

The network is completed by adding garage-origin arcs (g,i) , destination-garage arcs $(n+i, g')$ and the arc (g',g) which ensures flow in the network.

With the notation $O = \{1, 2, \dots, n\}$ and $D = \{n+1, \dots, 2n\}$, the structure of the network is:

$$[N ; A] = [\{g\}, O, D, \{g'\} ; \{g\} \times O, I, D \times \{g'\}, (g',g)] \quad (2)$$

The mathematical formulation has five major components:

the objective function

The objective to be minimized includes transportation costs and inconvenience to clients.

Transportation costs c_{ij} are constant and are calculated using travel times t_{ij} . If the number of vehicles is fixed, corresponding upper and lower bounds are associated with the arc (g',g) . Otherwise, the cost on this arc is equal to the cost of bringing out another vehicle while keeping only the upper bound on the arc.

Bodin and Sexton [1, 2, 6] define client inconvenience as a weighted sum of the deviation of real arrival time from desired arrival time $(\beta_{n+i} - t_{n+i})$,

and of the excess travel time over the minimum possible $(t_{n+1} - t_1 - t_{1,n+1})$.

With flow variables $x_{ij} \geq 0$, the objective function takes the form:

$$\text{Min } a_1 \sum_{ij \in A} c_{ij} x_{ij} + a_2 \sum_{i=1}^n (\beta_{n+1} - t_{n+1}) + a_3 \sum_{i=1}^n (t_{n+1} - t_1 - t_{1,n+1}) \quad (3)$$

network constraints

Each origin and destination node is visited exactly once:

$$\sum_j x_{ij} = \sum_j x_{ji} = 1 \quad i = 1, 2, \dots, 2n \quad (4)$$

$$x_{ij} \geq 0, \text{ and integer} \quad (i, j) \in A \quad (5)$$

scheduling constraints

$$\alpha_i \leq t_i \leq \beta_i \quad i = 1, 2, \dots, 2n \quad (6)$$

$$t_1 + t_{1,n+1} \leq t_{n+1} \quad i = 1, 2, \dots, n \quad (7)$$

$$x_{ij} > 0 \Rightarrow t_1 + t_{1j} \leq t_j \quad (i, j) \in I \quad (8)$$

The visiting times at nodes must fall within desired time intervals (6).

A client must be picked up before being delivered (7); this constraint can be eliminated if

$$\alpha_{n+1} + t_{n+1,1} > \beta_1$$

Finally the conditional relations (8) express the necessary compatibility between routes and scheduling.

capacity constraints

It is sufficient to satisfy capacity constraints at the origin to be certain they will be satisfied at destinations; so the capacity variables c_i $i = 1, 2, \dots, 2n$ must satisfy the equations:

$$0 \leq c_i \leq C \quad i = 1, 2, \dots, n \quad (9)$$

$$x_{ij} > 0 \Rightarrow c_i + \gamma_j = c_j \quad (i, j) \in I \quad (10)$$

chain constraints

Finally, a set of constraints must be added to ensure that pick-up and delivery of a client are carried out by the same vehicle.

This formulation consists of a network problem with several additional rather awkward constraints: the scheduling (6,8) and capacity (9,10) constraints which are essentially of the same type, the precedence constraints (7) and the chain constraints. There exists no optimal solution method for this formulation. Bodin and Sexton [2] use a sequential non-optimal decomposition of the problem. They construct a priori groups of requests satisfying all the constraints for a single vehicle, and then apply an approximate improvement method for each vehicle.

3. A SERVICE WITH TRANSFER CENTERS

3.1 Organization

The productivity of vehicles could be improved by using transfer centers. Several vehicles could pick up handicapped persons, arrive at the same time at a transfer center, exchange passengers and drive them to their destinations.

A vehicle could therefore pick up all the people in the same area leaving around the same time, even if they had different destinations. In the same way, people going to adjacent destinations at the same time could be transported by the same vehicle after the transfer, regardless of their departure point. Using transfer centers, two requirements rather than three are necessary to allow people to be transported by the same vehicle. This should increase occupancy of the vehicles and productivity, without imposing unacceptable detours on passengers.

The present service is organized in a short period and sometimes even during operations, while routes are being constructed and modified. Decisions are grouped into a single problem which is not easy to solve as previous studies have shown [1,2,6]. The use of transfer centers divides the problem into organizational and operational decision problems. A first organizational decision concerns the location of transfer centers. These centers would need to be developed and would not be moved in the medium term. The schedule for exchanges could also be fixed. A fixed schedule would encourage people to synchronize their movements and would result in a more efficient service. On the other hand, with variable exchange schedules, the service would be adapted to client requests. These decisions could be investigated taking into account the performance of the vehicles and service to clients.

A large part of the demand is known in advance and provides a basis for the construction of routes while certain special requests and cancellations arrive at the last minute. It would be much easier with a transfer center system to respond to occasional requests. For example, for a morning request with a time constraint for arrival at work, the last vehicle delivering in time for work in the work zone would be used. This choice determines the time at which the person

must be at the transfer center. For pick-up the arriving vehicle which passes closest to the individual's home would be chosen. For requests with departure time constraints a symmetric process would be used. It is easy to envisage that when a vehicle is full or when the route is too long, requests could be moved to other vehicles in the same general area or an additional vehicle could be added.

3.2 Construction of routes

For a given time and transfer point, two similar but independent route construction problems must be solved: one for pick-up and one for delivery. Each problem consists of visiting a certain number of points within given time intervals while minimizing the number of vehicles and the distance travelled.

For the pick-up problem, a set of origins O_k is associated with each transfer center k and meeting time β_k . The network:

$$[N_k^p, A_k^p] = [\{g\}, O_k, \{k\} ; \{g\} \times O_k, I_k^p, O_k \times \{k\}, (k, g)] \quad (11)$$

is constructed by the same rule as (1). This produces the following mathematical formulation:

$$\text{Min } \sum_{ij} \sum_{A_k^p} c_{ij} x_{ij} \quad (12)$$

$$\text{network constraints } \begin{cases} \sum_j x_{ij} = \sum_j x_{ji} = 1 & i \in O_k \\ x_{ij} \geq 0, \text{ integer} & (i, j) \in A_k^p \end{cases} \quad (13)$$

$$(14)$$

$$\begin{array}{l}
 \text{scheduling} \\
 \text{constraints}
 \end{array}
 \left[\begin{array}{ll}
 \alpha_1 \leq t_1 \leq \beta_1 & i \in O_k \quad (15) \\
 x_{ij} > 0 \Rightarrow t_i + t_{ij} \leq t_j & (i,j) \in I_k^p \quad (16) \\
 x_{ik} > 0 \Rightarrow t_i + t_{ik} \leq \beta_k & i \in O_k \quad (17)
 \end{array} \right.$$

$$\begin{array}{l}
 \text{capacity} \\
 \text{constraints}
 \end{array}
 \left[\begin{array}{ll}
 0 \leq c_i \leq C & i \in O_k \quad (18) \\
 x_{ij} > 0 \Rightarrow c_i + \gamma_j = c_j & (i,j) \in I_k^p \quad (19)
 \end{array} \right.$$

In comparison to the formulation without transfer centers we note the disappearance of precedence and chain constraints. The objective function is also slightly different: the third term is eliminated a priori by the association of a request for transportation with a time and transfer point which ensures a given level of service, and the second term is dealt with implicitly during the construction of routes [3].

The new objective function departs from the current philosophy of the service which orients route construction around individualized service, and favours a significant improvement in global performance with the same fleet of vehicles.

The construction of delivery routes proceeds mathematically in the opposite direction. The time interval associated with each node in the network is reversed.

$$[\alpha_{n+1}, \beta_{n+1}] := [-\alpha_{n+1}, -\alpha_{n+1}] \quad (20)$$

and the number of people associated with each destination $n+1$ is the positive integer γ_1 . The delivery network associated with center k is constructed as follows with these new time intervals (the direction of the arcs are thus opposite to their real direction):

$$[N_k^d, A_k^d] = [\{g'\}, D_k, \{k\} ; \{g'\} \times D_k, I_k^d, D_k \times \{k\}, (k, g')]$$
 (21)

The mathematical formulation is similar to that for the pick-up problem.

3.3 Solution

In practice, if transfers take place every 30 minutes during rush hours, capacity constraints will be useless because of the need to respect tight schedules. In the same way, when the demand is low, the capacity constraints will again be practically useless. The method described in [3] should therefore be easily adaptable to the problem.

The problem of visiting the nodes of a network while minimizing both the size of the fleet and distances travelled subject to scheduling constraints, can be solved optimally by Dantzig-Wolfe decomposition, or more specifically by column generation. The network constraints are divided into two parts: the subproblem is formed with the flow conservation and time constraints, while the master problem includes only the requirement to visit each node only once. The master problem is a covering problem which is solved by simplex. The subproblem is a shortest path problem with scheduling constraints on the nodes [4] solved by dynamic programming; it serves to generate as needed new columns or feasible routes for the covering problem. In this approach, the integrality of the flow variables is relaxed; a column generation strategy oriented towards feasible solutions enables an integer optimal solution to be obtained rapidly through a branch-and-bound tree.

Tests of this approach in the context of a school transportation problem showed that computation time for a problem with 48 tasks (or trips) to be linked, was 20 seconds on a CDC CYBER-173. The average length of the time windows associated with each node was around 25% of the horizon, i.e. there was 20 minutes flexibility in the departure time in comparison with the duration of the entire operation which was about 90 minutes. In this application, 14 to 17 vehicles were sufficient to accomplish all tasks where 19 has been necessary when departure times were fixed a priori. The size and characteristics of a pick-up or delivery problem for a given time at a transfer center would be very similar, e.g. around ten vehicles serving 50 requests.

The formulation of the pick-up and delivery problems is insufficient for the complete solution of the problem of transportation of the handicapped. Some additional logistical problems exist e.g. the location of the transfer centers, the establishment of transfer schedules, the assignment of clients to centers and some mixed problems where at the same time as delivering or picking up people passing through the transfer point, handicapped people taking short trips in the same direction are picked up and delivered. These various problems will be analyzed in detail after examination of some real data.

4. CONCLUSION

The use of transfer centers presents a potential performance improvement in the transportation of the handicapped which merits evaluation. This new approach to the organization of services fits in well with the fact that many origins and destinations are common to handicapped people: hospitals, universities, etc. In addition, this approach simplifies the route construction problem by decomposing it.

The solution approach proposed for the routing problem produces high quality results and the reduction in vehicles required is frequently quite considerable, if desired. If not, the algorithm functions with a fixed fleet size while improving the quality of service offered to users in terms of time spent travelling. This method provides a way of estimating optimal operating costs, vehicle performance and quality of service under the hypothesis of a system with transfer centers. Results calculated on past demand data could be compared with the actual performance of the current system over the same period.

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(1) Ecole des Hautes Etudes Commerciales de Montréal
 5255 ave. Decelles
 Montréal, Québec
 Canada H3T 1V6

(2) Centre de recherche sur les transports
 Université de Montréal
 Case Postale 6128, succ. A
 Montréal, Québec
 Canada H3C 3J7